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SPACE SHIFT KEYING WITH MRC AND ML DETECTIONS

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ABSTRACT :

Space shift keying (SSK) is a new modulation scheme that is based on spatial modulation (SM).This technique provides better performance over conventional amplitude/phase modulation (APM) techniques by exploiting the problem of fading which would result in loss of information for multiple-input multiple-output(MIMO) system . In this type of modulation,there is no transmission of the data symbols. However, the index of transmitting antenna is transmitted, resulting in advantages such as a reduction in detection complexity and hardware cost as there is no need for Amplitude Phase Modulation (APM) elements at both transmitting and receiving end. In the receiving side, the performance of the SSK modulated MIMO system consisting of N_t transmitters and N_r receiving antennas with STBC ,MRC and ML detectors is studied.Further the expression of ABER is derived using ML detection.The performance of the SSK modulated system is analyzed for the three detection algorithms.

Keywords:*-SSK,STBC,ML,MRC,SM*

INTRODUCTON :

Spatial modulation was introduced in order to avoid inter channel interference, to get rid over inter antenna synchronization(IAS),reduces the complexity of the system and also enhances the spectral efficiency compared to other MIMOtechniques.SSK modulation is the special case of SM.It is a technique in which the antenna indices are used.The antenna indices are transmitted to relay the information.As the data symbols are not transmitted,this method does not need the transceiver elements that are required for transmission and reception APM(Amplitude/Phase Modulation).Therefore the system complexity for SSK is less than SM as there is no need of using transceiver elements during transmission and detection.

SYSTEM MODEL:

Single Receiving Antenna:

In this system,two transmitting antennas and a single receiving antenna are used.As in SSK,at a particular instant of time only a single transmitting antenna will be in the state of action and the rest of the transmitting antennas will be in sleep mode.Therefore,here we are considering two states when 0 is the data to be transmitted and when 1 is the data to be transmitted.

Fig 1.1 refers to the instant of time at which Tx1 is in active state and Tx2 is in sleep mode when data bit 0 is transmitted and Fig 1.2 refers to the instant of time at which Tx2 is in active state and Tx1 is in sleep mode when data bit 1 is transmitted .

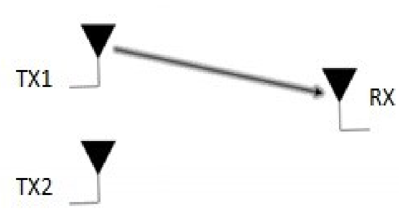

Fig 2 When transmitting data= 0, single receiving antenna

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Fig 3 When transmitting data= 1, single receiving antenna

MULTIPLE RECEIVING ANTENNAS :

It is the system in which two transmitting antennas and multiple receiving antennas are considered.When 0 is the data to be transmitted,then Tx1 is in active state and Tx2 is in sleep mode and therefore Tx1 transmits the antenna indices to all the receivers.Similarlly When 1 is the data to be transmitted,then Tx2 is in active state and Tx1 is in sleep mode and therefore Tx2 transmits the antenna indices to all the receivers.

Fig 1.3 refers to the instant of time at which Tx1 is in active state and Tx2 is in sleep mode when data bit 0 is transmitted and Fig 1.4 refers to the instant of time at which Tx2 is in active state and Tx1 is in sleep mode when data bit 1 is transmitted

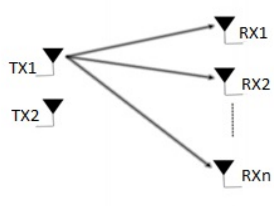

Fig 4 When transmitting data= 0, Multiple receiving antennas

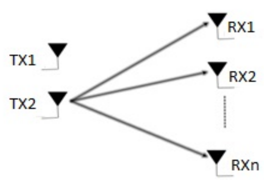

Fig 5 When transmitting data= 1, Multiple receiving antennas

BLOCK DIAGRAM

The general system model consists of a MIMO wireless link with N_t transmit and N_r receive antennas, which is illustrated in Fig.5.5. A random sequence of independent bits b=[$b_1 \quad b_2 \quad ... b_k$] enter a channel encoder with output c=[$c_1 \quad c_2 \quad ... c_n$] , where k and n represent the number of encoder inputs and outputs, respectively. The pseudo randomly interleaved sequence C^{π} then enters an SSK mapper, where groups of m=$log_2^{N_t}$ bits are mapped to a constellation vector x=[$x_1 \quad x_2 \quad ... x_k \quad]^T$, with a power constraint of unity .

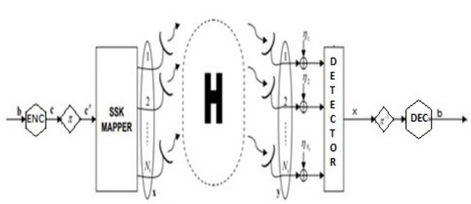

Fig 1.5 System Model

In SSK, one antenna remains active during transmission and therefore only one RF chain is required. Once the data is mapped into groups with the corresponding antenna indices.Then a signal is then transmitted over an $N_r * N_t$ wireless channel H, which experiences an additive white Gaussian (AWGN) noise n=$[n_1 \quad n_2 \quad \ldots n_{N_r}]^T$.The received signal is given by y=$\sqrt{E}$Hx+n, where E is the average signal to noise ratio (SNR) at each receive antenna, and H and n have independent and identically distributed (iid) entries accordingly whose mean=0 and variance=σ^2
At the receiver side, the SSK detector estimates the antenna index that is used during transmission, and then demaps the symbol to its component bits $\hat{b}$

TRANSMISSION :
SSK modulation consists of groups of m bits that are mapped to a symbol x_j, which is then transmitted from the j^{th} antenna. Although the symbol itself does not contain information, it is designed to optimize transmission. For now, we use x_j=1 for all j for optimized symbol transmission. Even though x_j does not convey information, its location in x does. The vector x specifies the activated antenna, during which all other antennas remain in sleep state, and has the following form:

$$x_j=[0\ 0 \ldots\ 1\ \ 0 \ldots\ \ 0]^T$$

Only one column of H is activated, and the column changes accordingly depending on the transmitted symbol.These columns act as random constellation points for SSK modulation.
An example of SSK modulation for 2 bits/s/Hz transmission is given in Table . In general, M-ary SSK modulation where log_2^M bits are transmitted per channel use requires N_t to be equal M.

MAPPING OF THE DATA BITS TO SSK SIGNALS FOR m=2 and $N_t = 4$

Data bits	SSK Tx Signal vector	Status of Tx antennas			
m=2	x	Antenna1	Antenna2	Antenna3	Antenna4
h_{11}=00	$[1\ \ 0\ \ 0\ \ 0]^T$	+1	OFF	OFF	OFF
h_{12}=01	$0\ \ 1\ \ 0\ \ 0]^T$	OFF	+1	OFF	OFF
h_{21}=10	$[0\ \ 0\ \ 1\ \ 0\ ]^T$	OFF	OFF	+1	OFF
h_{22}=11	$[0\ \ 0\ \ 0\ \ 1]^T$	OFF	OFF	OFF	+1

SIGNAL DETECTION TECHNIQUES :
MRC(Maximum Ratio Combining):
MRC is a technique of Combining all the signals in a co-phased and weighted manner so as to have the highest achievable SNR at the receiver at all times. In MRC, all the branches are used simultaneously.The multiple antenna system model can be vectorized as

$$\begin{bmatrix} y^1 \\ y^2 \end{bmatrix} = \begin{bmatrix} h^1 \\ h^2 \end{bmatrix} x + \begin{bmatrix} n^1 \\ n^2 \end{bmatrix}$$

$$y^1 = h^1 x + n^1$$

$$y^2 = h^2 x + n^2$$

Hence,the compact vector system model is

$$\bar{\boldsymbol{y}} = \bar{\boldsymbol{h}}\boldsymbol{x} + \bar{\boldsymbol{n}}$$

Receive Combining
We combine the two received symbols (y^1, y^2). Let these two be combined to produce the decision statistic $\tilde{y}$ as

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$$\tilde{y} = w^1y^1 + w^2y^2$$
$$=[w^1w^2]\begin{bmatrix} y^1 \\ y^2 \end{bmatrix}$$
$$\tilde{y} = \bar{w}^H\bar{y}$$

w1,w2 are the corresponding weights

Here $w=\begin{bmatrix} w^1 \\ w^2 \end{bmatrix}$, $y=\begin{bmatrix} y^1 \\ y^2 \end{bmatrix}$

Substitute $\bar{y} = \bar{h}x + \bar{n}$

We get $\tilde{y} = \bar{w}^H(\bar{h}x + \bar{n})$

$$\tilde{y} = \bar{w}^H\bar{h}x + \bar{w}^H\bar{n}$$

Therefore,the SNR is given as,

$$\text{SNR}=\frac{\text{SignalPower}}{\text{NoisePower}}=\frac{|\bar{w}^H\bar{h}|^2P}{E\{|\bar{w}^H\bar{n}|^2}$$

Noise Power:

To simplify the noise component $E\{|\bar{w}^H\bar{n}|^2$consider ,

$$\bar{w}^H\bar{n} = [w^1w^2]\begin{bmatrix} n^1 \\ n^2 \end{bmatrix}$$

$$\text{E}\{(w^1n^1 + w^2n^2)^2\} = \text{E}\left\{w^{1^2}n^{1^2} + w^{2^2}n^{2^2} + 2w^1w^2n^1n^2\right\}$$

n is a noise vector which is statistically independent.

So variance is constant and Mean=0

$$\text{E}\left\{n^{1^2}\right\} = \sigma^2 \quad \text{E}\left\{n^{2^2}\right\} = \sigma^2 \quad \text{E}\{(n^1)(n^2)\} = 0$$

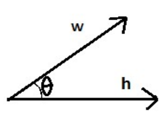
$$\text{E}\{(w^1n^1 + w^2n^2)^2\} = w^{1^2}\sigma^2 + w^{2^2}\sigma^2 + 0$$

Noise Power $= \sigma^2\|w\|^2$

Consider the signal component $|\bar{w}^H\bar{h}|$

$$\bar{w}^H\bar{h} = [w^1w^2]\begin{bmatrix} h^1 \\ h^2 \end{bmatrix}$$

$\bar{w}.\bar{h}=|w||h|\cos\theta$

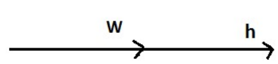


$\cos\theta$is the angle between vectors w,h as shown

$$\text{SNR}=\frac{\text{SignalPower}}{\text{NoisePower}}=\frac{P\|w\|^2\|h\|^2cos^2\theta}{\sigma^2\|w\|^2}$$
$$=\frac{P\|h\|^2cos^2\theta}{\sigma^2}$$

SNR is max when $cos^2\theta$ is equal to 1

Vectors w and h are aligned as shown



The maximum SNR is

$$\text{SNR}=\frac{P\|h\|^2}{\sigma^2}$$

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Since w and h are along the same line $w \propto \bar{h}$
Let c be the proportionality constant
$\bar{w} = c\bar{h}$
For optimal condition $\bar{w}$ is chosen such that

$\|\bar{w}\|^2 = 1 \qquad \|c\bar{h}\|^2 = 1$

$$\bar{w} = \frac{\bar{h}}{\|h\|}$$

Maximal ratio combiner is also called as Matched filter because when channel vector(h) equals to weighted vector we have chosen randomly it forms a matched filter

Maximum SNR: $\frac{P\|h\|^2}{\sigma^2}$

ML DETECTION:

For the detection of transmitted signal, ML detector has been used, which is as written below

$$y = arg \min_{j=1,2} \left(\left|y - \sqrt{E}h1\right|^2\right)$$

Assuming that, the data symbol to be transmitted is 0, resulting in the activation of Tx1. The received signal in this case can be written as

$y_r = y_1 = \sqrt{E}$h+n

If y_1 is the received signal, therefore, using ML detection method, the error can be defined as

P_e=P_r($\left|y_r - \sqrt{E}h_1\right|^2 > \left|y_r - \sqrt{E}h_2\right|^2$)

P_e=P_r($\left|\sqrt{E}(h_1 - h_2)\right|^2 < \hat{n}$

Where $\hat{n}$=2$\sqrt{E}\{(h_1 - h_2)n^*$

The variance of $\hat{n}$ can be computed as, σ^2=¶E($\hat{n}^2$) , where, E is an Expectation operator.Therefore,

$$\sigma^2 = 4E\frac{N_0}{2}|h1 - h2|^2 = 2EN_0|h1 - h2|^2$$

Hence, the Conditional Error Probability or Conditional Bit Error Rate (CBER) is defined as

$$P_r[n > a] = Q\left(\frac{a - \mu}{\sqrt{\sigma^2}}\right)$$

where, µ is the mean which is assumed as zero,

$$P_e = Q\left(\frac{E|h1 - h2|^2}{\sqrt{2EN_0|h1 - h2|^2}}\right)$$

therefore, CBER can be computed as

$P_e = Q\left(\sqrt{\frac{E|h1-h2|^2}{2N_0}}\right)$=Q$\left(\frac{E|H|^2}{2N_o}\right)$

Where H=$|h_1 - h_2|$

Now, CBER can be expressed in terms of γ as

Pe = Q($\sqrt{\gamma}$) where, $\gamma = \frac{E|h_1-h_2|^2}{2N_o} = \frac{E|H|^2}{2N_o}$,

and Q(x) is a gaussian Q function defined as

Q(x) =$\frac{1}{\sqrt{2\pi}}\int_x^\infty$ exp $\left(\frac{-t^2}{2}\right) dt$

Probability Density Function (PDF) :

The PDF of γ can be derived as follows

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Firstly, the PDF of h is to be calculated where, h = x + jy (x is real part and y is the imaginary part). Therefore, the joint PDF of x; y i.e f_{XY}(x; y) can be written as

$$f_{XY}(x,y)=\frac{1}{\sqrt{2\pi\sigma_X^2}}\exp^{\frac{-(x-m)^2}{2\sigma_X^2}}\frac{1}{\sqrt{2\pi\sigma_y^2}}\exp^{\frac{-(y-m)^2}{2\sigma_y^2}}$$

where, m is the mean, which has been considered zero for this analysis, m = 0 and σ^2 is the variance which is considered equal for both x and y $\sigma_X^2=\sigma_Y^2=\sigma^2$

Therefore

$$f_{XY}(x,y)=\frac{1}{2\pi\sigma^2}\exp^{\frac{-(x+y)^2}{2\sigma^2}}$$

Now, converting the above equation to polar co-ordinates.

Assuming a=$|h|^2=\sqrt{x^2+y^2}$ $\theta=\tan^{-1}\frac{y}{x}$

$$f_{A\theta}(a,\theta)=\frac{1}{2\pi\sigma^2}\exp^{\frac{-a}{2\sigma^2}}J_{(x,y)}$$

where, $J_{(x;y)}$ is the Jacobian of x,y which comes out to be , $J_{(x;y)=a}$

$$f_{A\theta}(a,\theta)=\frac{a}{2\pi\sigma^2}\exp^{\frac{-a}{2\sigma^2}}$$

The individual PDF of can be written as

$$f_A(a)=\frac{a}{\sigma^2}\exp^{\frac{-a^2}{2\sigma^2}}$$

The above equation can be written in terms of x as follows

$$f_X(x)=\frac{x}{\sigma^2}\exp^{\frac{-x^2}{2\sigma^2}}.$$

As $\gamma=\frac{E|h|^2}{2N_0}$ .Therefore applying the Cummulative Distribution Function(CDF)

$$F_X(x)=P_r[X<x]$$

$$F_X(x)=P_r\left[\frac{E|h|^2}{2N_0}<x\right]$$

Let it assumed that $\frac{E}{2N_0}=d$

therefore

$$F_X(x)=P_r\left[d\left|h^2\right|<x\right]$$

$$f_X(x)=F'_X(x)=\frac{1}{\frac{E\sigma^2}{2N_0}}\exp^{\frac{-x}{\frac{E\sigma^2}{2N_0}}}$$

PDF can further be computed as

$$ABER=\int_0^\infty Q(\sqrt{\Upsilon})\frac{1}{\overline{\Upsilon}}\exp^{\left(\frac{-x}{\overline{\Upsilon}}\right)}$$

AVERAGE BIT ERROR RATE(ABER):

The ABER can be computed by averaging CBER given in (2.8) over the PDF of . Since H is circularly symmetric, Gaussian distributed and is Rayleigh distributed. Subsequently, its PDF can be written as

$$f_\Upsilon(\Upsilon)=\frac{1}{\overline{\Upsilon}}\exp^{\left(\frac{-\Upsilon}{\overline{\Upsilon}}\right)}$$ where

$$\overline{\Upsilon} = E(\Upsilon) = E\left(\frac{E\left|h_1 - h_2\right|^2}{2N_0}\right) = E\left(\left|\frac{H^2}{2N_0}\right|\right) = \frac{E\sigma^2}{N_0}$$

Therefore

$$ABER = \int_0^{\infty} P_e(\Upsilon) f_{\Upsilon}(\Upsilon) d\Upsilon$$

On substituting $f_{\gamma}(\gamma)$ in ABER , we get

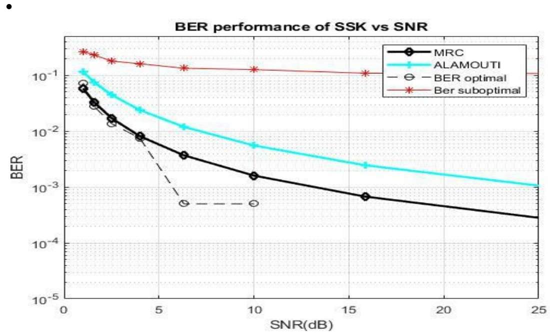
$$ABER = \int_0^{\infty} Q(\sqrt{\Upsilon}) \frac{1}{\overline{\Upsilon}} \exp^{\left(\frac{-x}{\overline{\Upsilon}}\right)}$$

On integrating further ,ABER can be computed as

$$ABER = \frac{1}{2}\left(1 - \sqrt{\frac{\overline{\Upsilon}}{2+\overline{\Upsilon}}}\right)$$

$$ABER = \frac{1}{2}\left(1 - \sqrt{\frac{\overline{\Upsilon}/2}{1+\overline{\Upsilon}/2}}\right)$$

SIMULATION RESULT :



We observe that initially the performance of the three detectors is similar .i.e., the corresponding value of BER for SNR=1db is equal (0.1) for all the three detectors.
For the value of SNR=2db, the difference between the Alamouti scheme with the other two techniques is very less (i.e. 0.05 db), whereas MRC and ML have same BER initially.
As the value of SNR increases correspondingly the deviation of Alamouti graph with the remaining two techniques gradually increases and till an optimal value of 4db, the two latter techniques have similar values.
Later, the graph deviates such that the slope of ML is very high as compared to the prior detectors.
This proves that, for a give SNR, the Bit Error Rate of ML detector system is very very less as compared to that of MRC which is comparatively less to that of Alamouti
Comparison of Alamouti,MRC & ML(SNR vs BER)

S.No	SNR(db)	Alamouti	MRC	ML
1.	1	0.1	0.1	0.1
2.	2	0.08	0.03	0.03
3.	3	0.04	0.015	0.013
4.	4	0.025	0.008	0.008

5.	6	0.016	0.004	0.0004
6.	10	0.007	0.001	0.0004

CONCLUSION :

A new modulation method referred to as SSK has been introduced for MIMO wireless links by exploiting the inherent fading process. Rather than transmitting information through symbols, the transmitter antenna indices were used as the sole information conveying mechanism. Throughout the paper, we laid out SSK fundamentals as the building ground for hybrid modulation schemes .All of SM's merits mentioned in are also inherent in SSK (at similar performance), but with lower computational overhead, and greater design flexibility. These advantages make SSK a promising candidate for low complexity transceivers in next generation communication systems.

FUTURE SCOPE :

Future research directions will involve the adaptive case, where SSK's constellation can take advantage of channel conditions. The three different detectors namely Maximal Ratio Combining(MRC) and Maximum Likelihood Detectors(Optimal & Sub-Optimal) has been plotted and the performance is studied. It has been concluded that ML is the best technique of all the detection mechanisms.

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